

Diversity and dynamics of microarthropods from different biotopes of Las Sardinias cave (Mexico)

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ABSTRACT

An ecological study of the microarthropod communities from Las Sardinias cave was undertaken. Four different biotopes were studied over the course of a year: bat guano, litter, soil under the chemoautotrophic bacteria colonies and as a control, plain soil without litter or guano. A total of 27,913 specimens of a total of 169 species were collected. Analysis of Variance (ANOVA) showed that there is a significant effect of biotope on the recorded density, and the post hoc Tukey's test showed that guano is the most different biotope with the highest value of density recorded. The interaction between season and biotope variables was not significant. In the most extreme case, 99 percent of the microarthropods in soil under chemoautotrophic bacteria were mites, mainly in the family Histiostomidae.

Key words: Cave communities, distribution, energy fluxes, food resources, microarthropods

INTRODUCTION

Caves are environments with relatively stable climatic conditions, compared to those outside. This environment is characterized by the lack of light and very often limited food resources, usually coming from the outside, via streams, gravity, feces of animals or their own remains. But those with big populations of bats can produce large amounts of guano that in many cases are used as fertilizer.

Most animals living inside caves, were considered as "cavernicolous" (Barr 1963), and others as accidental. Among cavernicoles there are troglloxenes, trogllophiles or troglobites according to their life cycle, in agreement to Schinner-Racovitza classification (Racovitza 1907). The number of species living exclusively in the subterranean environments has been estimated between 50,000 and 100,000 (Culver and Holsinger 1992), and the invertebrates, mainly arthropods, constitute the majority of cave animals (Gibert and Deharveng 2002).

Springtails (Collembola) and mites (Acari) are the most diverse and abundant microarthropods in soils and other subterranean environments. They play such an important role in the trophic webs that some authors consider them as the "subterranean plankton" (Ginet and Decou 1977). The movements and dispersion routes of this fauna have been better understood after the discovery of the "milieu souterrain superficiel" (Juberthie et al. 1981). The vertical migration of the animals from surface to caves has been also explained thanks to their transpor-

tation through the microcaves of the superficial environment, and the movement of carbon from the soil to the superficial subterranean environment (Gers 1998). The most important energy flow in caves is input of particulate organic carbon or dissolved organic carbon in water (Simon and Benfield 2001; Simon et al. 2007).

The vast geologic diversity of Mexico makes it very interesting for speleological studies. About 20% of the Mexican territory is karst and more than 1,200 caves have been recorded, and some are among the deepest caves of the World (Lazcano 1983, Espinasa 1990, Arias 2001).

Therefore, Mexico is very attractive for biospeleological research. There is a rich cave fauna and their representatives present interesting adaptations for this peculiar environment. Compilation of all the information about the Mexican fauna has been done by Reddell (1981) and Hoffmann et al. (2004). The most interesting species for their adaptation to cave life were listed by Palacios-Vargas (1994).

The State of Tabasco, which is located in the South of Mexico, is a region with well developed karst (Espinasa 1990), and the fauna of 14 Tabascan caves have been recorded (Reddell 1981). Cueva de Las Sardinias is located on "Villaluz" Ranch, in a small relict of what was once a rich tropical rain forest. Villaluz Ranch is located about two kilometers from Tapijulapa town, in Southeastern Mexico.

The first scientific record about this cave dates back to 1944, when Stirling collected flatworms of the genus *Dugesia*, fish of genus *Poecilia*, trichodactylid crabs of

the species *Trichodactylus bidens*, one amblypid of the genus *Phrynos*, several genera of spiders such as *Tetragnatha*, *Maymena* and *Eidmanella*, and one hemipteran of the genus *Belostoma*.

Gordon and Rosen (1962) made a systematic study about the fishes from Las Sardinias and their adaptations to cave life. They also cited three species of bats: *Mormoops megalophylla* Peters, *Pteronotus davyi* Gray and *Pteronotus parnellii* Gray. In 1998, Gamboa and Kú made the first topographical description of the cave and gave a list of the surroundings vegetation. Mejía and Palacios-Vargas (2001) collected 31 specimens of *Poecilia sphenops*, among which there was a pregnant female with 15 embryos. Stomach contents of those specimens were analyzed and some arthropods and plant remains were observed. They also recorded ostracods (possible *Cyclocypris*) and one crab (*Avotrichodactylus bidens* Bott).

Hose and Pisarowicz (1999) made a complete and detailed description of this cave which included a map. The importance of Las Sardinias, as a special environment was pointed out by Hose (1999) who described several of the bacteria living there. The bacteria described by Hose and Pisarowicz (1999) are chemoautotrophic, and the secretions of their colonies were called “snottites” because of their appearance. Chemoautotrophic bacteria survive without sunlight, and take energy from an exothermic reaction, in which sulfidric acid is broken down into sulfuric acid. The products of this natural reaction increase the erosion of cave walls. This process was named “replacement solution” by Egeimer (1981). This process produces deposition of the sulfur and gypsum on the walls and ceiling of the cave which are very heavy and weak, and easily crumbles and is dissolved by water very quickly.

The sulfur-eating bacteria constitute the base of the food webs. This was discovered for the first time in the

Movile cave in Romania, where the ecosystem is chemoautotrophically based (Sarbu and Popa 1992, Sarbu et al. 1996). The difference of Movile cave and Cueva de Las Sardinias is that the Mexican cave has three different supplies of energy: guano from the bat colonies, litter and other detritus which fall through the different skylight holes (originated by the action of acids) and the “snottites”, the bacteria colonies. Movile was a closed old system and Las Sardinias is a relatively new and open system.

Several studies of arthropods in Las Sardinias cave have been done, but they are mainly taxonomic (Estrada and Iglesias 2003; Estrada and Mejía-Recamer 2005; Palacios-Vargas and Estrada 2003; Palacios-Vargas et al. 2009) or morphological (Fuentes et al. 2007), but very few of them are related to communities and dynamics. This study mainly focuses on communities and the position of different groups in the complex food chains or trophic web existing in the cave. The study was done during one year and allowed us to make an inventory of the fauna living in this cave.

MATERIALS AND METHODS

Four different biotopes, including the control biotope were studied in the cave for terrestrial communities, which were chosen in twelve different chambers along the cave. They were: a) bat guano; b) litter, debris with soil associate to skylights; c) soil under bacteria colonies; d) soil as control, principally limestone (Fig. 1).

The sampling was done every three months, from March 2001 to March 2002. Twelve samples were taken each time (one from each chamber), every sample was about 600 cm³ and all of them were put in plastic boxes and taken to the laboratory. In the laboratory the samples were processed by Berlese-Tullgren funnels to extract the microarthropod specimens. Specimens were stored in

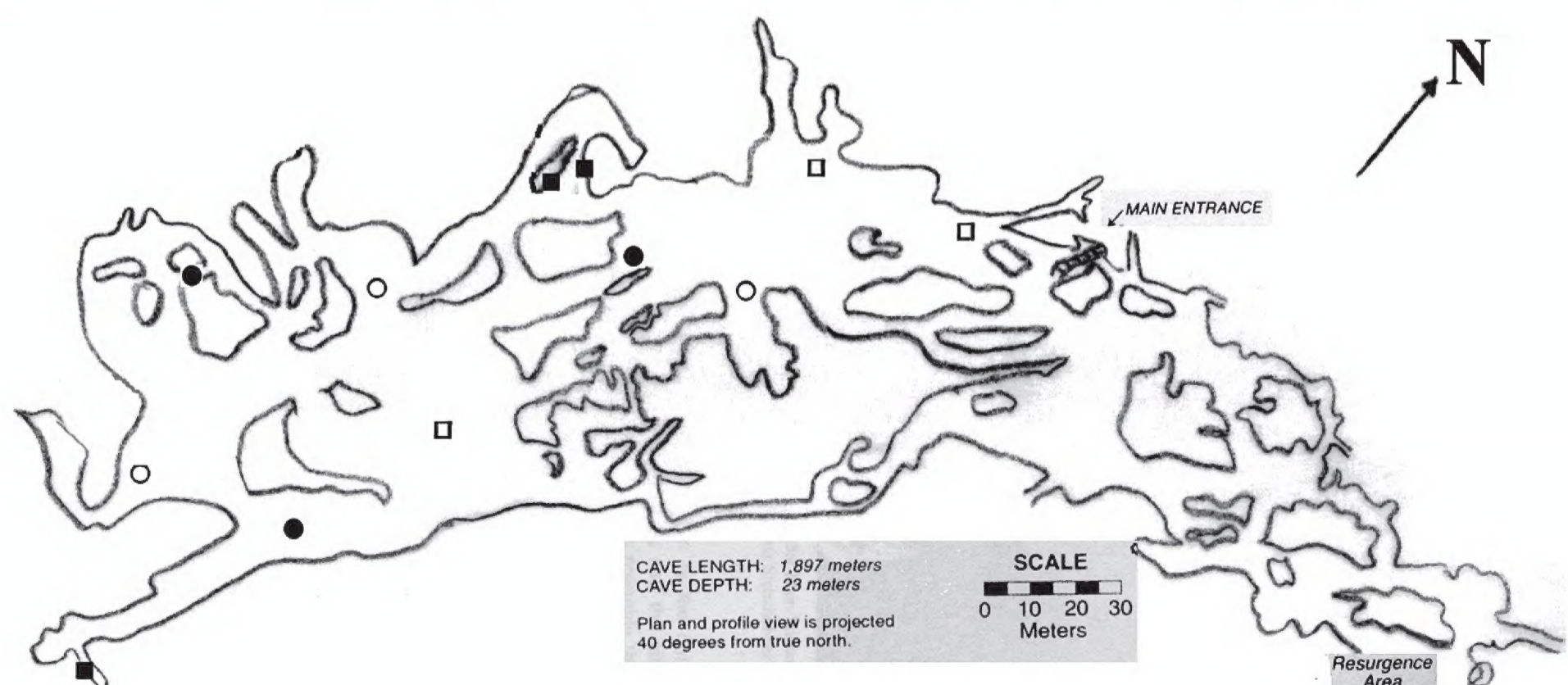


Fig. 1 - Map of the Las Sardinias cave with the location of the samples stations. ■ Bat guano, □ Litter, ● Soil under bacteria colonies and ○ Soil control (Map modified from Hose et al. 2000)

75% alcohol. After that, they were isolated by morphospecies and counted in order to obtain the abundance and the diversity index for each season of the year. For the identification, many specimens of each morphotype were cleared and mounted in Hoyer's solution.

Species richness (S), Shannon diversity ($H' = \sum p_i \ln p_i$) and Pielou's evenness ($J' = H' / \ln S$) indices were calculated. Diversity index were compared between pairs with a t test modified (Magurran 1988; Zar 1984), using PAST software (Hammer et al. 2001). An analysis of variance (ANOVA) was used to evaluate the effect of biotope and that of the season on the density of microarthropods. The affinity of the species to the biotopes was studied with cluster analysis, using the dissimilarity rate (difference between two percentage distributions) as a distance and graphically represented using UPGMA as the aggregation method. All analyses were performed using STATISTICA 5.0 software (Statsoft 1996).

According to the available bibliographic information about the biology of the spotted species, the feeding relationships were inferred in order to show the potential trophic relationships in the cave. In some cases information observed in field on feeding behavior was recorded, as well the gut content observed in slides preparations of microarthropods.

RESULTS AND DISCUSSION

A total of 27,913 specimens were collected (Table 1). The largest number was taken from guano (21,422; 7 individuals m^{-3}), followed by litter (4,455; 1.5 individuals m^{-3}), the soils with the bacteria colonies (1,614; 0.5 individuals m^{-3}) and control soil (422; 0.1 individuals

m^{-3}). ANOVA (Table 2) showed a significant effect of the biotope upon the microarthropod density ($F_{3,40} = 25.67$, $p < 0.0001$), the *post hoc* Tukey test ($p < 0.001$) showed that guano differs from the others biotopes in the density of organisms (Table 3). The interaction between season and biotope variables was not significant, that means that the arthropod density does no change depending on the biotope according to the date (Date: $F_{4,40} = 0.60$, $p > 0.05$; interaction: $F_{12,40} = 1.25$, $p > 0.05$).

Twenty-four microarthropod species were found in soil under the bacteria colonies, forty-four in the control soil, fifty-seven in the guano and one hundred and thirty-six in the litter. The total number of species of this cave was 169. The variation in the number of species in each biotope through the year is shown in Fig. 2.

The most important results of our studies are: 99% of the microarthropods in soil under the chemoautotrophic bacteria colonies were mites, 80% belongs to the cohort Astigmatina (mainly family Histiostomidae), 15% to the Oribatei (mainly family Oppiidae) and only 4% of order Mesostigmata. The remaining arthropods were mainly pseudoscorpions and spiders.

In the control soil, the mites represent 81% microarthropods; among them 38% are Astigmatina (also mainly of the family Histiostomidae). Then, the order Trombidiformes is represented by 22% (mainly the predatory family Cunaxidae) and the other groups are similar to those in the soil under the chemoautotrophic bacteria.

The litter has the highest diversity of microarthropods, but mites are again the dominant group (79%). Among mites, Astigmatina represent 43%, but one important difference is that there were at least 15 morphospecies of Oribatei and 12 of Mesostigmata, almost twice the number found in the other biotopes. Collembola oc-

Table 1 - Abundance of microarthropods, by biotope, found on "Las Sardinas" cave. Trophic groups: B = Bacteriophagous; D = Depredator; F = Phytophagous; L = Litter feeder (Panphytophagous); M = Mycophagous; N = Nematophagous; O = Omnivorous; P = Parasite; S = Scavenging; ND = No Determinate.

Phylum Arthropoda	Litter	Bat Guano	Soil under bacteria colonies	Soil control	Trophic Group	Feeding habit reference
Class Arachnida						
Order Pseudoscorpiones	2	7	11	17	D	De Andrade and Gnaspini 2002
Family Chernetidae	6				D	Johnson and Wellington 1980
<i>Cordylochernes</i> sp.		247			D	Taxa generalized
<i>Lustrochernes</i> sp.		19			D	Taxa generalized
Family Lechytiidae						
<i>Lechytia</i> sp.		2			D	Taxa generalized
Family Olpiidae			1		D	Taxa generalized
Family Syarinidae						
<i>Ideoblothrus</i> sp.	10		1	4	D	Taxa generalized
Order Schizomida	2				D	Taxa generalized

Phylum Arthropoda	Litter	Bat Guano	Soil under bacteria colonies	Soil control	Trophic Group	Feeding habit reference
Order Araneae						
Family Dipluridae	2	2			D	Jiménez 1998
Family Linyphiidae	19				D	Harwood et al. 2001
Family Mimetidae	6				D	Kloock, 2001
Family Pholcidae	3	1				Jiménez 1998
Family Salticidae	27		3	19	D	Jiménez 1998
Order Opiliona	1				D	Santos and Gnaspini 2002
Subclass Acari						
Order Ixodida						
Superfamily Ixodoidea						
Family Ixodidae	1				P	Taxa generalized
Family Argasidae						
<i>Antricola</i> sp.	7	43			C, P	De la Cruz and de Armas 1990
Order Mesostigmata						
Morphospecies 1	9				ND	
Morphospecies 2	1				ND	
Morphospecies 3	6			2	ND	
Suborder Sejida						
Superfamily Sejoidea						
Family Sejidae						
<i>Sejus</i> sp.		11	67	19	D	Walter and Proctor 1998
Suborder Trigynaspida						
Cohort Antennophorina						
Superfamily Celanopsoidea						
Family Diplogyniidae		6			F	Hunter 1993
Superfamily Megisthanoidea						
Family Megisthanidae	3				F, N	Hunter 1993
Suborder Monogynaspida						
Cohort Uropodina						
Subcohort Uropodidae						
Superfamily Uropodoidea	1				L, H	Nawar et al. 1993
Family Metagynuridae						
<i>Metagynella</i> sp.		13		5	L	Taxa generalized
Family Uropodidae						
<i>Uropoda (Phaulodinychnus)</i> sp.	11	12931			L	Vazquez and Klompen 2007
Family Trematuridae						
<i>Trichouropoda</i> sp.		21			L, M	Lindquist et al. 2009
Cohort Gamasina						
Subcohort Dermanyssiae						
Superfamily Rhodacaroidea						
Family Ologamasidae						
<i>Gamasellus</i> sp.	1	1		1	D	Lister et al. 1998
Family Rhodacaridae						
<i>Rhodacarus minimus</i>	81				D, N	Sardar and Murphy 1987
Superfamily Eviphidoidea						
Family Macrochelidae						
<i>Glyptholaspis</i> sp.		392		7	D	Lindquist et al. 2009
Superfamily Ascoidea						
Family Ascidae						
<i>Gamasellodes</i> sp.	1	1424	2		D, N	Walter 1987 ^a

Phylum Arthropoda	Litter	Bat Guano	Soil under bacteria colonies	Soil control	Trophic Group	Feeding habit reference
Family Melicharidae						
<i>Proctolaelaps</i> sp.			1		D	Lindquist et al. 2009
Superfamily Phytoseioidea						
Family Blattisociidae						
<i>Lasioseius</i> sp.	199			6	D, M, N	Walter and Lindquist, 1989
Family Phytoseiidae		140			D	McMurtry and Croft 1997
Superfamily Dermanyssoidea						
Family Laelapidae						
<i>Gaeolaelaps</i> sp.	47	5			D, N	Walter and Oliver 1989
<i>Hypoaspis</i> sp.	4				D	Taxa generalized
Family Macronyssidae				1	P	O'Connor 1998
Order Trombidiformes						
Morphospecies 1	3	1		4	ND	
Morphospecies 2	2	1			ND	
Morphospecies 3	20				ND	
Morphospecies 4	1				ND	
Morphospecies 5	1				ND	
Morphospecies 6				1	ND	
Suborder Prostigmata						
Supercohort Eupodides						
Superfamily Bdelloidea						
Family Cunaxidae						
<i>Coleoscirus</i> ca. <i>breslauensis</i>	22	10	2	3	D, N	Walter and Kaplan 1991
<i>Coleoscirus</i> ca. <i>simplex</i>	9			1	D, N	Walter and Kaplan 1991
<i>Cunaxoides</i> ca. <i>nicobarensis</i>	3				D	Fain et al. 1993
<i>Cunaxoides</i> sp.	16	654			D	Fain et al. 1993
<i>Dactyloscirus</i> sp. 1	4		15	25	D	Taxa generalized
<i>Dactyloscirus</i> sp. 2	6		1		D	Taxa generalized
<i>Neoscirula</i> ca. <i>luxtoni</i>	4				D	Taxa generalized
<i>Neoscirula</i> ca. <i>delareyi</i>	1				D	Taxa generalized
<i>Neoscirula</i> sp.	6		1	18	D	Taxa generalized
<i>Pseudobonzia</i> sp.	39		1	4	D	Taxa generalized
<i>Pulaeus</i> ca. <i>pectinatus</i>	1				D	Taxa generalized
<i>Pulaeus</i> sp. 1	10	616		3	D	Taxa generalized
<i>Pulaeus</i> sp. 2	29	7			D	Taxa generalized
Superfamily Eupodoidea						
Family Rhagidiidae						
<i>Robustocheles</i> sp.	1				D	Taxa generalized
Supercohort Trombidiae						
Superfamily Trombidioidea		13		1		Azevedo et al. 2002
Superfamily Trombiculoidea						
Family Neotrombidiidae		2			P	Taxa generalized
Supercohort Eleutherengonides						
Cohort Heterostigmata						
Superfamily Tarsonemoidea						
Family Tarsonemidae	2	2			L, F	Estebanes-Gonzalez 1997
Order Sarcoptiformes						
Suborder Endeostigmata						
Cohort Alycina						
Superfamily Alycoidea						
Family Nanorchestidae	31			11	L, M	Walter 1987b
Suborder Oribatida						

Phylum Arthropoda	Litter	Bat Guano	Soil under bacteria colonies	Soil control	Trophic Group	Feeding habit reference
Supercohort Palaesomatides						
Superfamily Palaecaroidea	2				L	Taxa generalized
Supercohort Enarthronotides						
Superfamily Hypochthonioidea						
Family Lohmanniidae						
<i>Javacarus (Euryacarus) pilosus</i>	6				L	Taxa generalized
Supercohort Mixonomatides						
Superfamily Euphthiracaroidae						
Family Euphthiracaridae	1				L	Taxa generalized
Superfamily Phthiracaroidae						
Family Phthiracaridae	13				L	Taxa generalized
Supercohort Desmonomatides						
Cohort Nothrina						
Superfamily Crotonioidea						
Family Malaconothridae						
<i>Malaconothrus ca. angulatus</i>	1				L	Palacios-Vargas and Iglesias 1997
<i>Malaconothrus ca. pervensis</i>	5				L	Palacios-Vargas and Iglesias 1997
<i>Malaconothrus ca. granulatus</i>	27				L	Palacios-Vargas and Iglesias 1997
<i>Malaconothrus (Cristonothrus) peruanensis</i>	29				L	Palacios-Vargas and Iglesias 1997
<i>Malaconothrus</i> sp.		3			L	Palacios-Vargas and Iglesias 1997
Cohort Brachypylina						
Superfamily Microzetoidea						
Family Microzetidae						
<i>Berlesezetes brazilozetoides</i>	1				L	Taxa generalized
Superfamily Gustaviodea						
Family Liacaridae						
<i>Cultroribula</i> sp.	1				L	Taxa generalized
Superfamily Carabodoidea						
Family Carabodidae						
<i>Cubabodes ca. radiatus</i>	39				L	Taxa generalized
Family Dampfiellidae						
<i>Beckiella</i> sp.	1				L	Taxa generalized
Superfamily Oppioidea						
Family Oppiidae						
Subfamily Oppiinae						
<i>Aeroppia ca. nasalis</i>	3				L	Taxa generalized
<i>Aeroppia nasalis</i>	11				L	Taxa generalized
<i>Aeroppia</i> sp.				1	L	Taxa generalized
<i>Amerioppia similis</i>	37			2	L	Taxa generalized
<i>Taiwanoppia (Vietoppia) sp.</i>	1				L	Taxa generalized
Subfamily Multioppiinae						
<i>Intermedioppia ca. alvarezi</i>	136		250	111	L	Guevara et al. 2002
Subfamily Mystroppinae	6			2	L	Taxa generalized
Subfamily Arcoppiinae						
<i>Similoppia (Reductoppia) sp.</i>		2			L	Subias and Rodriguez 1987

Phylum Arthropoda	Litter	Bat Guano	Soil under bacteria colonies	Soil control	Trophic Group	Feeding habit reference
Family Suctobelbidae						
<i>Suctobelbella</i> (<i>Flagrosuctobella</i>) <i>multiplumosa</i>	1				L	Taxa generalized
Superfamily Oriopodoidea						
Family Haplozetidae						
<i>Trachyoribates</i> (<i>Rostrozetes</i>) <i>foveolatus</i>	420	453			L	Taxa generalized
Family Scheloribatidae				1	L, M	Hubert et al. 2000
<i>Scheloribates elegans</i>	22				L, M	Hubert et al. 2000
<i>Scheloribates</i> sp.	95	1			L, M	Hubert et al. 2000
Superfamily Ceratozetoidea						
Family Ceratozetidae						
<i>Ceratozetes</i> sp.	2				L, M	Walter 1987b
Superfamily Galumnoidea						
Family Galumnidae						
<i>Galumna</i> ca. <i>hamifer</i>	66				L	Schatz 1998
<i>Galumna hamifer</i>	23				L	Schatz 1998
Cohort Astigmatina (Astigmata)						
Superfamily Histiotomatoidea						
Family Guanolichidae						
<i>Neoguanolichus</i> sp.	7	802	866	3	C	Fain 1979
Family Histiotomatidae						
<i>Histiotoma</i> ca. <i>himalayae</i>				5	B	Vreeken-Bujin et al. 1997
<i>Histiotoma</i> ca. <i>bakeri</i>	25				B	Vreeken-Bujin et al. 1997
<i>Histiotoma</i> ca. <i>piloseta</i>		1209			B	Vreeken-Bujin et al. 1997
<i>Histiotoma</i> ca. <i>sextoni</i>	293				B	Vreeken-Bujin et al. 1997
<i>Histiotoma</i> sp. 1	699	367	114	57	B	Vreeken-Bujin et al. 1997
<i>Histiotoma</i> sp. 2	5				B	Vreeken-Bujin et al. 1997
<i>Histiotoma</i> sp. 3	1				B	Vreeken-Bujin et al. 1997
<i>Histiotoma</i> sp. 4	109			5	B	Vreeken-Bujin et al. 1997
Superfamily Hemisarcoptoidea						
Family Winterschmidtidae						
<i>Winterschmidtia</i> sp.		2			F	Rodriguez-Navarro et al. 2003
Superfamily Glycyphagoidea						
Family Rosensteiniidae						
<i>Nycteriglyphus</i> sp.	4	8			L	OConnor 1998
Superfamily Acaroidea						
Family Acaridae						
<i>Rhizoglyphus</i> ca. <i>callae</i>	130	2		1	F	Díaz et al. 2000
<i>Rhizoglyphus</i> ca. <i>robini</i>	59	1			F, N	Estebanes-Gonzalez & Rodriguez-Navarro 1991
<i>Sancassania</i> ca. <i>mycophagus</i>	7	126	262	24	F	Estebanes-Gonzalez & Rodriguez-Navarro 1991
<i>Schwiebea</i> sp.	737	1	22	6	M	Okabe 1999
<i>Tyrophagus</i> ca. <i>neiswanderi</i>	10	1		1	M	Okabe 1999
<i>Tyrophagus</i> ca. <i>similis</i>		1			F, M	Okabe 1999
Class Crustacea						
Subclass Copepoda						
Order Harpacticoida	34				B	Rieper 1978
Order Isopoda	10				L	Reeves and McCreadie 2001

Phylum Arthropoda	Litter	Bat Guano	Soil under bacteria colonies	Soil control	Trophic Group	Feeding habit reference
Class Collembola						
Order Poduromorpha						
Superfamily Neanuroidea						
Family Neanuridae						
Subfamily Neanurinae						
<i>Americanura sardinasensis</i>	28				L, M	Taxa generalized
Subfamily Pseudachorutinae						
<i>Pseudachorutes</i> sp.	7				L	Taxa generalized
<i>Neotropiella quinqueoculata</i>	6				L, M	Taxa generalized
Family Odontellidae						
<i>Xenyllodes</i> sp.	1				L, M	Taxa generalized
Superfamily Hypogastruroidea						
Family Hypogastruridae						
<i>Ceratophysella</i> ca. <i>succinea</i>	1			1	L, M	Zettel et al. 2002
<i>Xenylla</i> ca. <i>humicola</i>		17		2	L, M	Castaño-Meneses et al. 2004
Superfamily Onychiroidea						
Family Tullbergiidae						
<i>Mesaphorura yosii</i>	36			1	L, M	Sabatini and Innocenti 2000
Order Entomobryomorpha						
Superfamily Isotomoidea						
Family Isotomidae						
Subfamily Anurophorinae						
<i>Cryptopygus</i> ca. <i>thermophilus</i>	15				L, M	Castaño-Meneses et al. 2004
<i>Cryptopygus thermophilus</i>	20				L, M	Castaño-Meneses et al. 2004
Subfamily Proisotominae						
<i>Folsomina onychiurina</i>	5				L, M	Taxa generalized
Subfamily Isotominae						
<i>Isotoma</i> sp.	18				L, M	Walter 1987b
<i>Isotomiella minor</i>	9				L, M	Taxa generalized
<i>Isotomurus retardatus</i>	15				L, M	Castaño-Meneses et al. 2004
Superfamily Entomobryoidea						
Family Entomobryidae				1	L, M	Castaño-Meneses et al. 2004
Subfamily Orchesellinae						
<i>Heteromurus major</i>	3				L, M	Scheu et al. 1999
Subfamily Entomobryinae						
<i>Entomobrya</i> sp.	9				L, M	Chen et al. 1996
Subfamily Lepidocyrtinae						
<i>Lepidocyrtus</i> sp.	1				L	Taxa generalized
<i>Pseudosinella</i> ca. <i>colina</i>	2			1	L, M	Walter 1987b
<i>Pseudosinella orba</i>	7			7	L, M	Walter 1987b
Family Paronellidae				2	L	Taxa generalized
Order Neelipleona						
Family Neelidae						
<i>Megalothorax minimus</i>	1				L	Taxa generalized
Order Symphypleona						
Superfamily Katiannoidea						
Family Katiannidae						
<i>Sminthurinus quadrimaculatus</i>		2			L	Taxa generalized
Family Arrhopalitidae						
<i>Arrhopalites</i> sp.	2				L	Taxa generalized
Superfamily Dicyrtomoidea						

Phylum Arthropoda	Litter	Bat Guano	Soil under bacteria colonies	Soil control	Trophic Group	Feeding habit reference
Family Dicyrtonidae						
Subfamily Ptenothricinae						
<i>Ptenothrix marmorata</i>	7				L	Taxa generalized
Class Symphyla	1				L	Umble and Fisher 2003
Class Insecta						
Order Microcoryphia		1	1		L	Taxa generalized
Order Zygentoma	1				L	Taxa generalized
Order Thysanoptera						
<i>Adraneothrips</i> sp.	6	1			M	Childers et al. 1998
<i>Zeugmatothrips priesneri</i>	20				F, M	Taxa generalized
Order Psocoptera	2				L, M	Taxa generalized
Order Hemiptera-Heteroptera	1				F	Taxa generalized
Order Homoptera-Homoptera	3	1	1	3	L, F	Taxa generalized
Order Coleoptera						
Larvae 1	19	416	2	8	ND	
Larvae 2	337				ND	
Larvae 3		6			ND	
Family Curculionidae	2				F	Navarrete-Heredia 2001
Family Histeridae						
<i>Hister</i> sp.		14			N, D	Moreno et al. 1998
Family Platypodidae		1			F	Equihua-Martínez et al. 1984
Family Ptiilidae	1				L, M	Navarrete-Heredia 2001
Family Scydmaenidae	1	2	1	4	D	O'Keefe 2000
Family Staphylinidae	2				D	Leschen and Newton 2003
<i>Anotylus</i> sp.	6				L, N, M, S	Jimenez-Sanchez et al. 1990
Order Lepidoptera		5			F	Taxa generalized
Order Diptera	9	22	2	3	L	Taxa generalized
Larvae 1	9	227			ND	
Larvae 2	19				ND	
Larvae 3	8	172			ND	
Larvae 4	22	4			ND	
Larvae 5	3				ND	
Family Chironomidae						
Larvae 1	11	767			L	Delettre 2000
Order Hymenoptera	1				F	Taxa generalized
Family Formicidae						
Subfamily Amblyoponinae						
<i>Prionopelta modesta</i>	24				D	Taxa generalized
Subfamily Myrmicinae						
<i>Lepto thorax</i> sp. 1	18				O	Fernández 2001
<i>Lepto thorax</i> sp. 2	10				O	Fernández 2001
<i>Solenopsis</i> sp. 1	29		1		D, O	Fernández 2001
<i>Solenopsis</i> sp. 2	3				D, O	Fernández 2001
<i>Strumigenys</i> sp.	2				D	Fernández 2001
<i>Tetramorium</i> sp.	2				D	Bendicho and Gonzalez 1986
<i>Wasmannia auropunctata</i>	2				D	Taxa generalized
Subfamily Ponerinae						
<i>Hypoponera</i> sp.	12					Taxa generalized
<i>Pachycondyla</i> sp.	1				D	Dejean 1990

Table 2 - Results of ANOVA test to evaluate the effect of biotope and collecting date on the microarthropods density from Las Sardinas Cave, Tabasco Mexico. * $p < 0.05$. $N = 40$

Source	F	Df	p
Biotope	25.67	3	0.0001*
Date	0.60	4	0.10
Interaction	1.25	12	0.20

Table 3 - Average density of microarthropods (ind/cm³) from Las Sardinas Cave, Tabasco Mexico. Different letters denote differences according with *post hoc* Tukey's test.

Biotope/Date	Average \pm sd
Soil under bacteria colonies	0.53 \pm 0.77a
Soil control	0.14 \pm 0.08a
Litter	1.48 \pm 0.99a
Bat Guano	7.09 \pm 3.99b

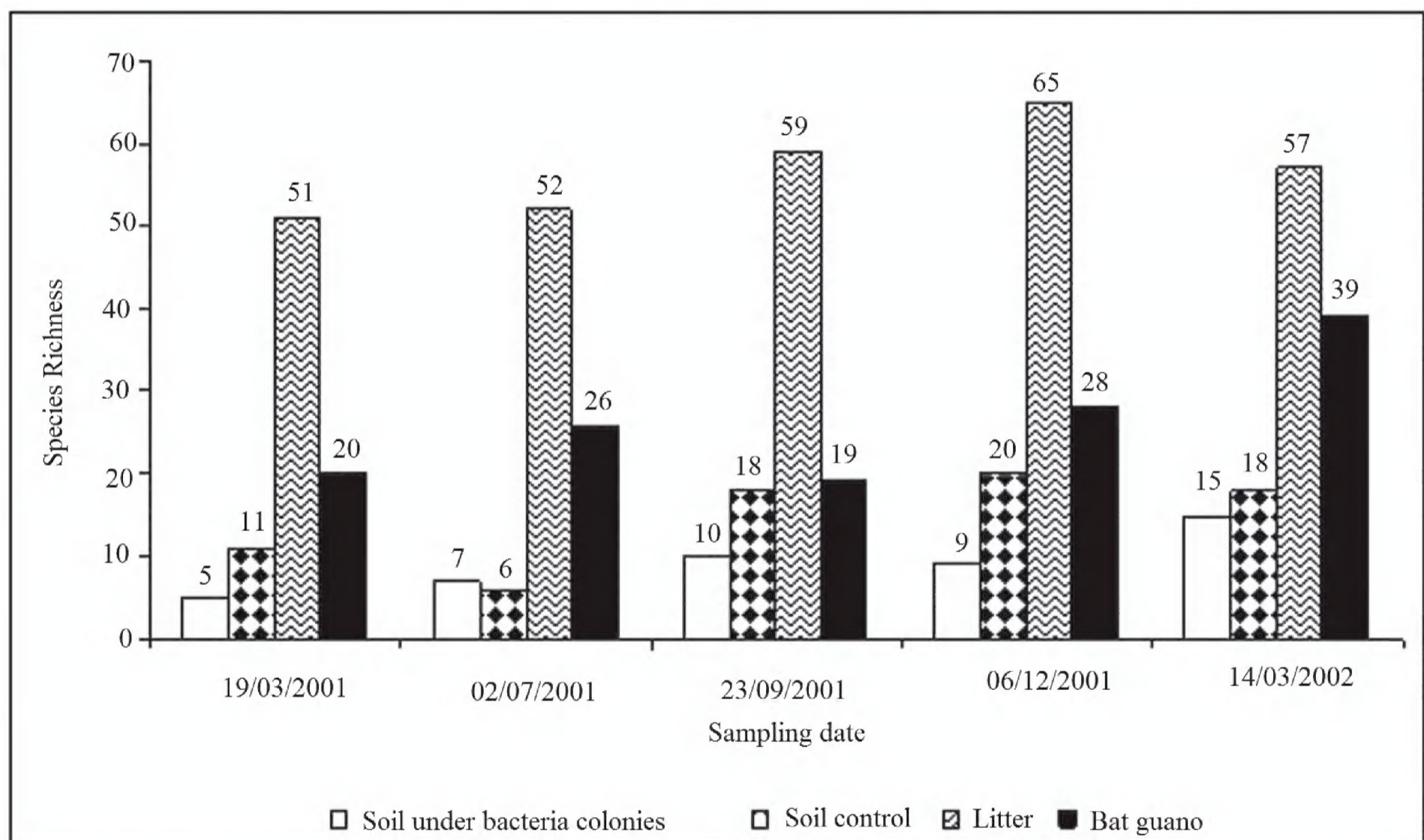


Fig. 2 - Number of species for each biotope at different dates in Las Sardinas cave, Tabasco, Mexico.

copy the sixth place after three different species of mites and one of Coleopteran larvae.

Guano has high abundance of Mesostigmata mites (79% of total microarthropods), followed by Dipteran larvae and Astigmatid mites (6% each taxon), and the Trombidiformes (mainly Cunaxidae 3%). Figs 3 and 4 show the most abundant microarthropods from different biotopes in the cave.

There were important and statistical significant differences among the biotopes except between diversity of the litter and control soils. This suggests that the biotopes of this cave have four independent communities,

in which the vegetal debris had the highest diversity according to the Shannon index ($H' = 3.34$), followed by the control soil ($H' = 2.85$), bat guano ($H' = 1.72$), and the soil under the bacteria ($H' = 1.43$). The evenness follows more or less the same pattern, but the guano communities present the lowest value in evenness ($J' = 0.75$ plant debris > 0.68 control soil > 0.45 bacteria > 0.43 guano). The guano probably has the lowest diversity because it has different fauna depending on maturation and the high abundance of few species. The t test results have shown significant differences between all the diversity indexes recorded in the study (Table 4).

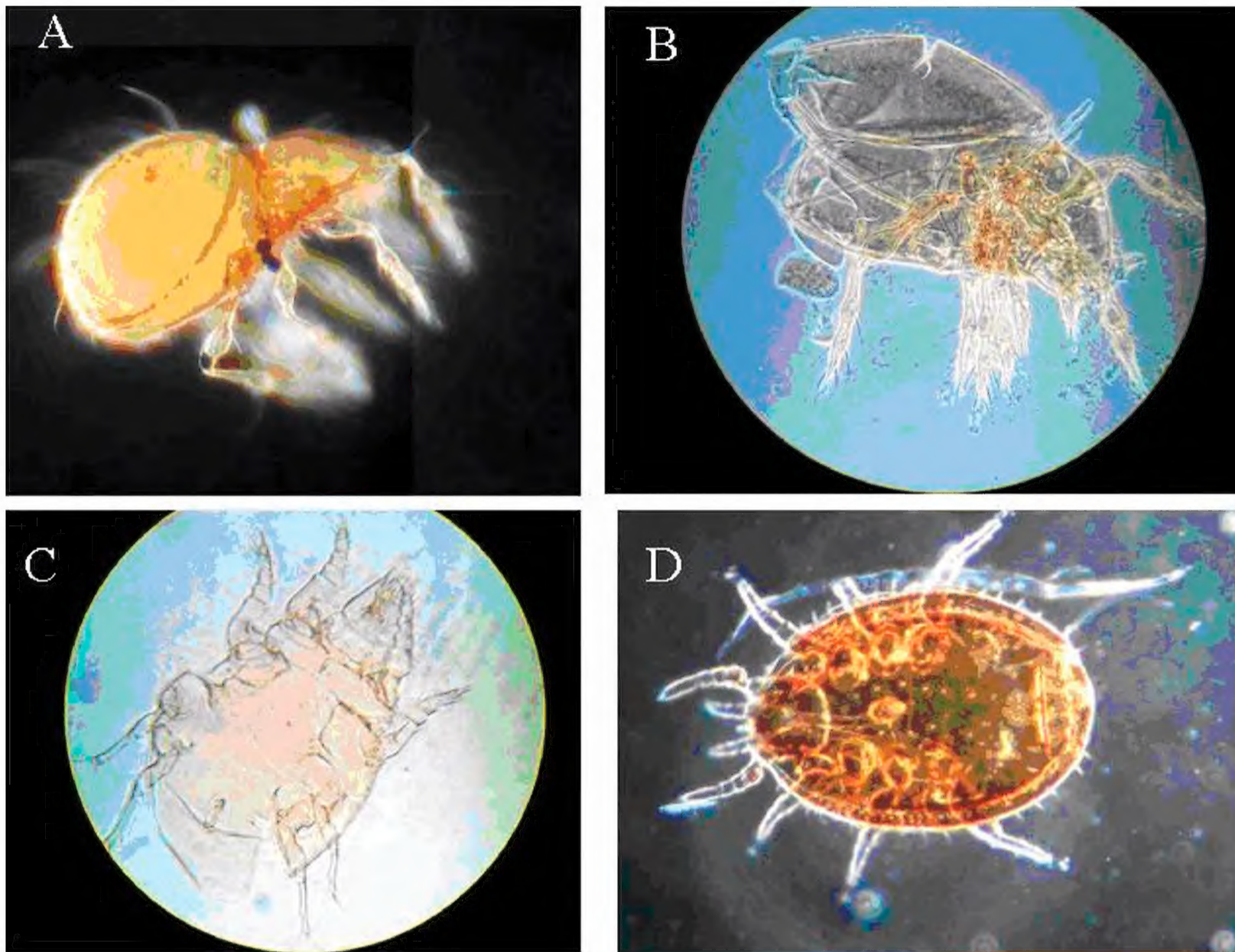


Fig. 3 - Mites found at Las Sardinas cave. A. Cryptostigmata: Oppidae; B. Cryptostigmata: Scheloribatidae; C. Astigmata: Histios-tomidae; D. Mesostigmata: Uropodidae.

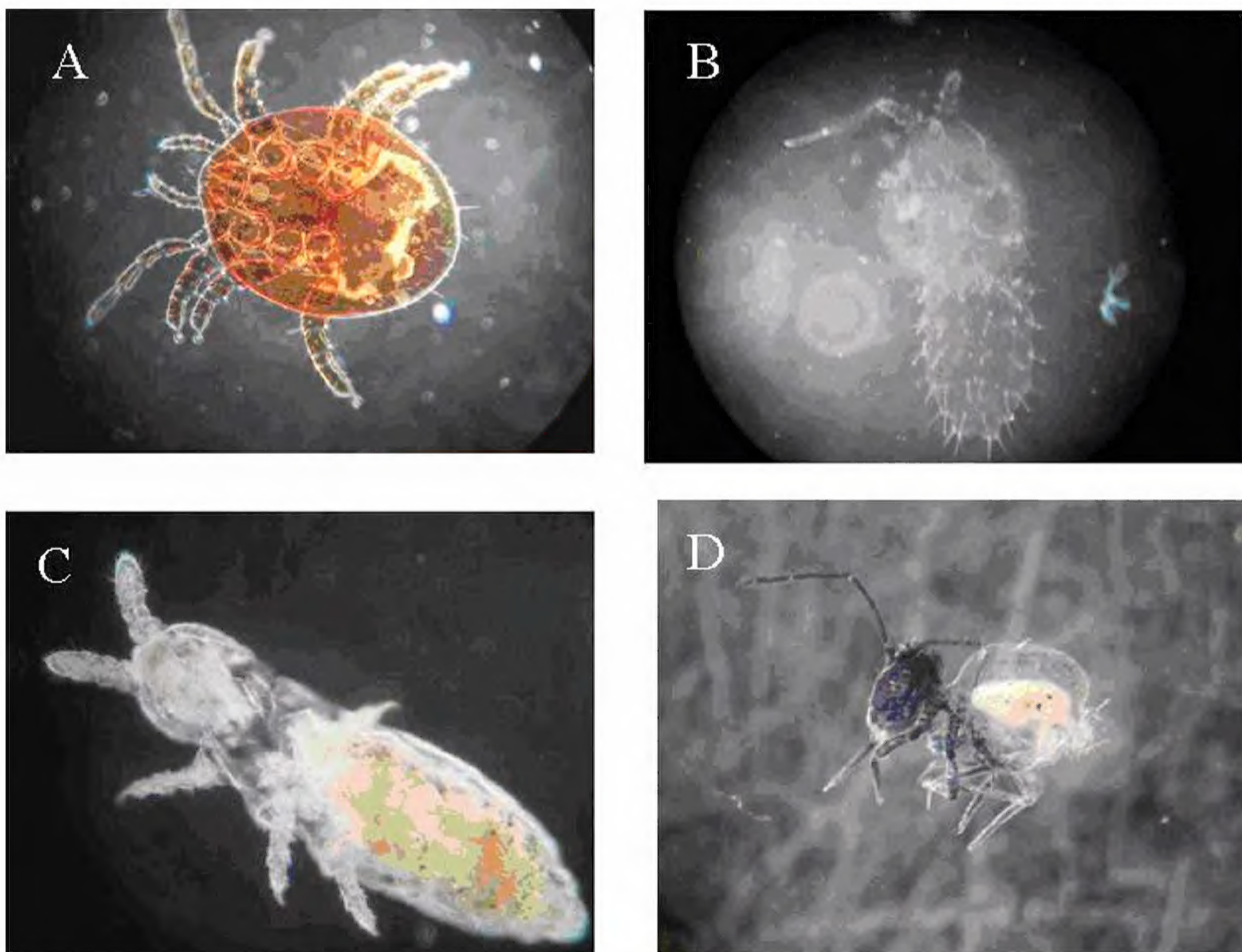


Fig. 4 - Mites and springtails from Las Sardinas cave. A. Mesostigmata: Uropodidae; B. Collembola: Neanuridae; C. Collembola: Hypogastruridae; D. Collembola: Dicyrtomidae.

Table 4 - Results of paired t test between diversity indices. Degree of freedom in parenthesis *p<0.05

Biotope	Soil under Bacteria	Soil control	Litter	Bat guano
Soil under Bacteria	-	19.54 (597)*	50.64 (4000)*	9.65 (2134)*
Soil control	19.54 (597)*	-	7.63 (547)*	16.55 (445)*
Litter	50.64 (4000)*	7.63 (547)*	-	60.08 (6322)*
Bat guano	9.65 (2134)*	16.55 (445)*	60.08 (6322)*	-

Cluster analysis used to compare the four biotopes in relation to the shared species shows isolation of the litter from the others biotopes. This is the biotope more different in species composition than the others. The other group is grouping the more similar biotopes in the cave and among these the soil under bacteria colonies, and control soil are more similar to each other than the guano (Fig. 5).

The species richness can be explained because of the great diversity of habitats within of Las Sardinias cave. Those habitats together along with other factors such as the vegetation around the cave (Gamboa and Ku 1998), and the connection with the environmental conditions of the area where the cave is located, play an important role in explaining diversity too. The presence of diverse

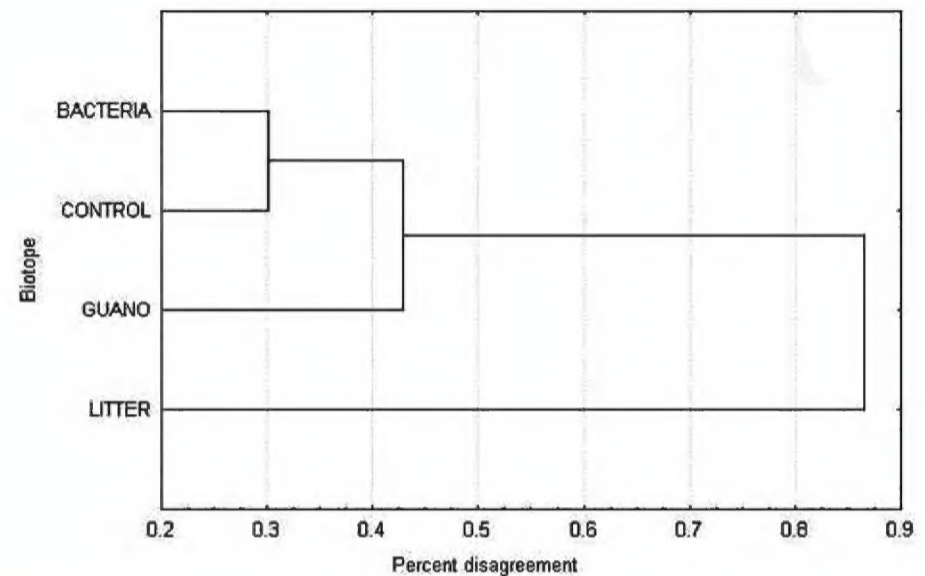


Fig. 5 - Cluster diagram showing the percent of disagreement of the biotopes according with its species composition.

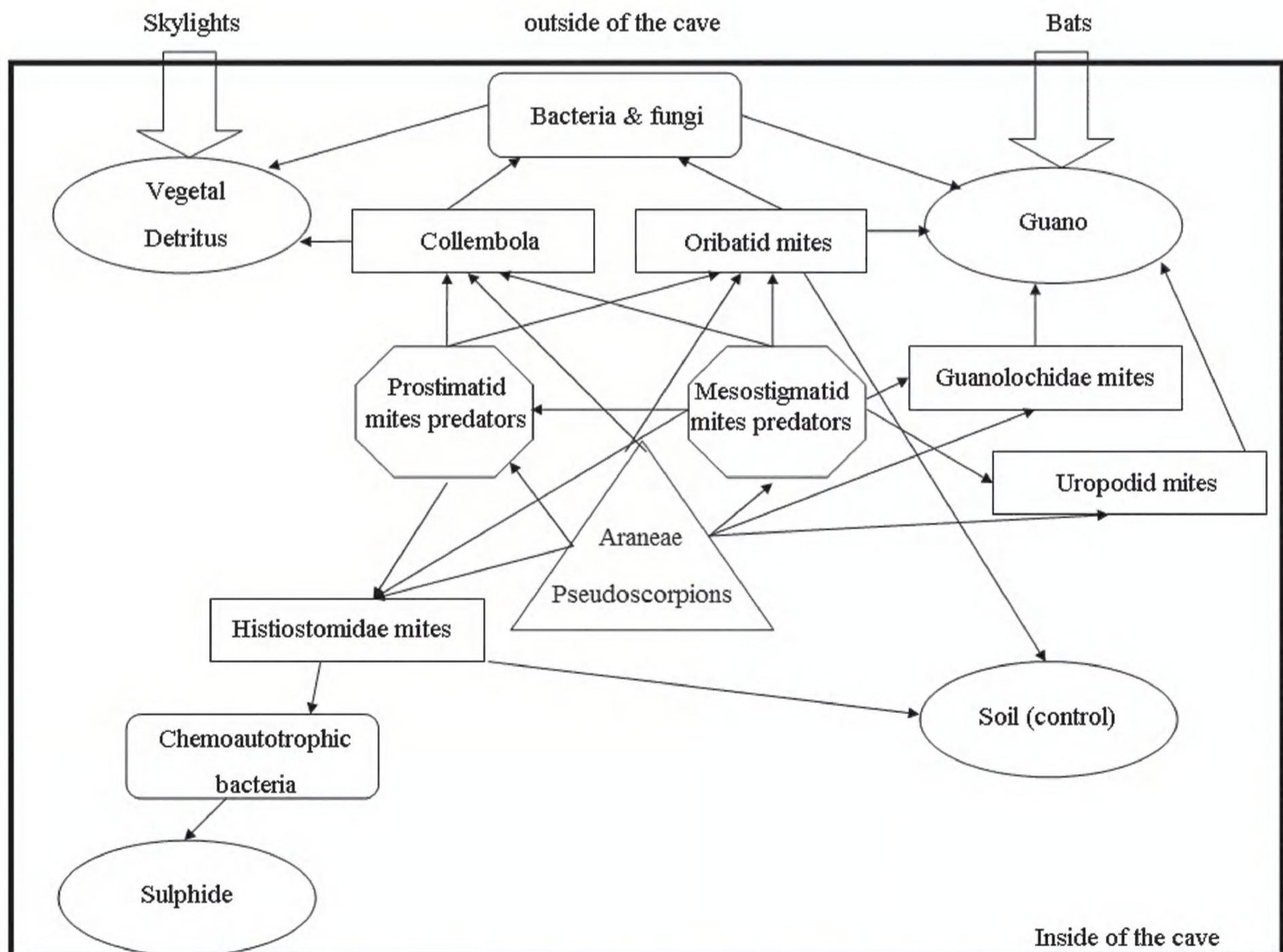


Fig. 6 - Proposed trophic web at Las Sardinias cave, Tabasco, Mexico. ○ = Energy source; □ = Microorganisms; □ = Arthropods first consumers; □ = Arthropods first predators; △ = Arthropods second predators.

sources of nutrients increases the resources availability that can be exploited by different microarthropods, increasing the possibility to support a diversity of communities. Studies about the diversity of habitats and species richness in caves suggest that, for the terrestrial animals, the local patterns of diversity are very important (Christman and Culver 2001).

Due to the different food resources in Las Sardinas cave, the food webs are very complex. There are four trophic levels which interact, and result in an increase of the energetic fluxes in the system. The main food resources are: plant detritus which come from the surrounding vegetation (Fig. 6). The other important food source is bat guano, and the bacteria colonies are less important. The plant detritus feeds many fungi and some bacteria which are consumed by many Collembola, Oribatid and Uropodid mites, most of them are preys of Prostigmata and Mesostigmata mites, ants, and different arachnids as spiders, pseudoscorpions, amblypygids, and the Scutigera centipides. The bat guano contains mites and Collembola very similar to those found at the vegetal detritus, but with some species very specialized as guanophiles.

One important remark is the fact that we found two other species of mormoopid bats (*Pteronotus personatus* and *Pteronotus gymnonotus*) which always form huge colonies. There are also other less abundant species in families Emballonuridae (possible *Baliantopterus*), Phyllostomidae (*Carollia*) and the vampire bat (*Desmodus rotundus* Thomas) in subfamily Desmodontinae, additional to the previous recorded species (Gordon and Rosen 1962).

CONCLUSIONS

This cave is by far the most diverse we have studied, with a least 169 terrestrial microarthropod species. The soil under the chemoautotrophic bacteria and the litter have the lowest value of the diversity index, while the guano has the largest microarthropod abundance. The species found belonging to the families Histiotomidae (Astigmata) and Oppiidae (Cryptostigmata) indicate they have the highest resistance to acid conditions of the environment.

Among microarthropods, the mites are the most abundant group, and Mesostigmata are the dominant group in presence. This result is very different of what is commonly found in the caves, where the springtails are usually the dominant group (Gers 1998). In our results, springtails occupy the sixth place in abundance, after Mesostigmata, Astigmata, Cryptostigmata, Prostigmata and Coleoptera larvae. The presence of many predatory mites suggests that the available resources in the cave can support higher trophic levels.

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REFERENCES

- Arias, R. 2001. Sótanos de México. Abismos de luz y sombra: México, Secretaría del Medio Ambiente y Recursos Naturales, México.
- Barr, T.C. 1963. Ecological classification of cavernicoles. Cave Notes 5: 9-12.
- Christman, M.C., D.C. Culver. 2001. The relationship between cave diversity and available habitat. Journal of Biogeography 28: 367-380.
- Culver, D.C., J.R. Holsinger. 1992. How many species of troglobites are there? National Speleological Society Bulletin 54: 79-80.
- De la Cruz, J & L. F. de Armas. 1990. Artículos alimentarios de las garrapatas de los géneros *Antricola* y *Parantricola* (Ixodoidea: Argasidae). Ciencias Biológicas Academia de Ciencias de Cuba 23: 118-121.
- Egeimer, S.J. 1981. Cavern development by thermal waters. The NSS Bulletin 43: 31-51.
- Espinasa, R. 1990. Propuesta para la clasificación del karst de la República Mexicana. Unpublished Professional thesis, Facultad de Ingeniería, Universidad Nacional Autónoma de México.
- Estrada, D.A., R. Iglesias. 2003. Biodiversidad de ácaros oribátidos (Acari: Cryptostigmata) de la cueva de "Las Sardinas", Tabasco, México. Entomología Mexicana 2: 46-52.
- Estrada, D.A., B.E. Mejía-Recamier. 2005. Cunaxidos de la Cueva de Las Sardinas, Tabasco, México. Memorias del VII Congreso Nacional de Espeleología, Monterrey, México, Febrero 2-6, p. 44-46.
- Fuentes, M., S. Espinosa-Matías, J.G. Palacios-Vargas. 2007. Mites Cunaxidae from Las Sardinas cave (Tabasco, Mexico) under the scanning electron microscope. Pp. 575-579 in J.B. Morales-Malacara, V. Behan-Pelletier, R. Ueckermann, T.M. Pérez, E.G. Estrada-Venegas, M. Baddi, eds. Acarology XI. Proceedings of the International Congress. Mexico: UNAM.
- Gamboa, V.J., L. Ku. 1998. Descripción de la cueva "Las Sardinas", Villa Luz, Tabasco, México. Mundos Subterráneos 9: 51-54.
- Gers, Ch. 1998. Diversity of energy fluxes and interactions between arthropod communities: from soil to cave. Acta Oecologica 19: 205-213.

- Ginet, R., V. Decou. 1977. Initiation with biology and ecology underground, Paris, University Editions J-P. Delarge.
- Gibert, J., L. Deharveng. 2002. Subterranean ecosystems: a truncated functional biodiversity. *BioScience* 52: 473-481.
- Gordon, M.S., D.E. Rosen. 1962. A cavernicolous form of the Poeciliid fish *Poecilia sphenops* from Tabasco, Mexico. *Coepia* 2: 360-368.
- Hammer, Ø., D. A. T. Harper, P. D. Ryan. 2001. Past: Paleontological Statistics software package for education and data analysis. *Paleontologia Electronica* 4 (1): 9 pp. http://paleo-electronica.org/2001_1/past/issue1_01.htm
- Hoffmann, A., M.G. López-Campos, I.M. Vázquez-Rojas. 2004. Los artrópodos de las cavernas de México. Pp. 229-328 in J.E. Llorente, J.J. Morrone, O. Yáñez, I. Vargas, eds. Biodiversidad, taxonomía y biogeografía de artrópodos de México: Hacia una síntesis de su conocimiento, vol. IV. México: CONABIO-UNAM.
- Hose, L.D. 1999. Exploring one of the world's strangest caves. *The Explorers Journal* (Spring): 22-27.
- Hose, L.D., J.A. Pisarowicz. 1999. Cueva de Villa Luz, Tabasco, Mexico: Reconnaissance study of an active sulfur spring cave and ecosystem. *Journal of Cave and Karst Studies* 61: 13-21.
- Hose, L. D., A. N. Palmer, M. V. Palmer, D. E. Northup, P. J. Boston, H. R. DuChene. 2000. Microbiology and geochemistry in a hydrogen-sulphide-rich karst environment. *Chemical Geology* 169 (3-4): 399-423.
- Hunter, P. E. 1993. Mites associated with New World passalid beetles (Coleoptera: Passalidae). *Acta Zoologica Mexicana Nueva Serie* 58: 1-37
- Juberthie, C., B. Delay, M. Bouillon. 1981. Sur l'existence d'un milieu souterrain superficiel en zone calcaire. *Mémoires de Biospéologie* 8: 77-93.
- Lazcano, C. 1983. México paraíso de la espeleología. *Gaceta UNAM*, 1 (41): 21.
- Lister, A., W. Block, M. B. Usher. 1988. Arthropod predation in an Antarctic terrestrial community. *Journal of Animal Ecology* 57(3): 957-970.
- Lindquist, E. E., G. W. Krantz, D. E. Walter. 2009. Order Mesostigmata. Pp. 124-232 in Krantz, G. W., D. E. Walter, eds. *A Manual of Acarology*, Third edition. Texas Tech University Press. Lubbock.
- Magurran, A. E. 1988. Ecological diversity and its measurement. Princeton University Press, New Jersey, USA.
- Mejía-Ortiz, L.M., J.G. Palacios-Vargas. 2001. Estigofauna de la cueva de Las Sardinias, Tabasco, México. *Mundos Subterráneos* 11-12: 10-17.
- Nawar, M. S., G. M. Shereef, M. A. Ahmed. 1993. Effect of food on development, reproduction and survival of *Chiroptuopoda bakeri* (Acarina: Uropodidae). *Experimental and Applied Acarology*. 17(4): 277-281.
- Palacios-Vargas, J.G. 1994. Mexique. Pp. 391-401 in: C. Juberthie, V. Decu, eds. - *Encyclopaedie Biospeologica*. Tome I, Cap. IV. Bucarest: Société de Biospeleologie.
- Palacios-Vargas, J.G., D. Estrada-Bárcenas. 2003. Comparación entre los colémbolos que habitan dentro de la cueva de Las Sardinias y las que viven en el exterior. *Memorias del VI Congreso Nacional de Espeleología*, Tuxtla Gutiérrez, Chiapas, México, Febrero 1-4: 11-14.
- Palacios-Vargas, J.G., J.C. Simón Benito, J. Paniagua Nucamendi. 2009. Especies nuevas de *Americamira* (Collembola: Neanuridae) de América Latina. *Revista Mexicana de Biodiversidad* 80: 431-443.
- Racovitza, E.G. 1907. Essai sur les problèmes biospéologiques. *Archives de Zoologie Expérimentale et Générale* 6: 371-488.
- Reeves, W.K. 2001. Invertebrate and slime mold cavernicoles of Santee Cave, South Carolina, USA. *Proceedings of the Academy of Natural Sciences of Philadelphia* 151: 81-85.
- Reddell, J.R. 1981. A review of the cavernicole fauna of Mexico, Guatemala, and Belize. Austin, Texas Memorial Museum.
- Sarbu, S.M., T. C. Kane and B. K. Kinkle. 1996. A chemoautotrophically based cave ecosystem. *Science*. New Series, 272: 1953-1955.
- Sarbu, M. & R. Popa. 1992. A unique chemoautotrophically based cave ecosystem, p. 637-666. In: *The natural history of biospeleology* (A.I. Camacho ed.); Monografías. Museo Nacional de Ciencias Naturales. Madrid.
- Simon, K.S. & E.F. Benfield. 2001. Leaf and wood breakdown in cave streams. *Journal of the North American Benthological Society* 20 (4): 550-563.
- Simon, K.S., T. Pipan and D.C. Culver. 2007. A conceptual model of the flow and distribution of organic carbon in caves. *Journal of Cave and Karst Studies* 69 (2) 279-284.
- StatSoft, Inc. 2006. *Electronic Statistics Textbook*. Tulsa, StatSoft. <http://www.statsoft.com>
- Vázquez, M.M. & H. Klompen. 2007. New records of Uropodina mites from México, Guatemala, Belize and Costa Rica. *Dugesiana* 14 (1): 27-37.
- Walter, D. E. & H. C. Proctor. 1998. Feeding behaviour and phylogeny: Observations on early derivative Acari. *Experimental & Applied Acarology*. 22 (1): 39-50.
- Zar, H. J. 1984. *Biostatistical analysis*. Second edition. Prentice Hall, Engelwood Cliffs, New Jersey.